

## Paleogeographic patterns of the Cambrian-Ordovician transition in the southern Montagne Noire (France) : preliminary results

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*Key words.* – Stratigraphy, Tectonism, Paleogeography, Cambrian, Ordovician, Montagne Noire.

*Abstract.* – The Cambrian-Ordovician transition in the southern Montagne Noire records a major siliciclastic regressive trend of prograding shoaling complexes (the La Dentelle Formation), separating two transgressive storm-dominated sedimentary systems of mixed (carbonate-siliciclastic) deposits. The latter comprise the underlying La Gardie and Val d'Homs Formations, and the overlying Mounio Formation, all of them displaying evidence of an important syndimentary tectonic activity. Isolated settings of carbonate productivity, located on intra-shelf ramps and horsts, contain the richest and diversified faunistic communities comprising trilobites, echinoderms, conodonts, carbonate- and phosphate-shell brachiopods, sponge spicules, etc. Although the Cambrian-Ordovician transition of the southern Montagne Noire did not record volcanic events but a rather distensive regime inducing paleotopographies, the latter may reflect a distinct extensional regime recorded in other earliest Ordovician platforms of the French Massif Central, involving oceanization and a major magmatic activity.

### Aperçu paléogéographique de la transition cambro-ordovicienne dans la Montagne Noire méridionale (France) : résultats préliminaires

*Mots clés.* – Stratigraphie, Activité tectonique, Paléogéographie, Cambrien, Ordovicien, Montagne Noire.

*Résumé.* – La transition cambro-ordovicienne de la Montagne Noire méridionale reflète une tendance régressive en milieux silicoclastiques, comprenant les complexes de barres hydrauliques de la formation de la Dentelle, délimités par deux systèmes sédimentaires mixtes (carbonato-silicoclastiques) transgressifs dominés par l'action des tempêtes. Ces systèmes correspondent respectivement aux formations sous-jacentes de la Gardie et de Val d'Homs, et à la formation sus-jacente de Mounio, qui ont enregistré une activité tectonique syndimentaire importante. Les communautés fauniques les plus riches et diversifiées (comprenant des trilobites, échinodermes, conodontes, brachiopodes à coquilles carbonatées et phosphatées, spicules d'éponges, etc.) occupent des emplacements très réduits. Ces communautés, associées à une forte productivité carbonatée, sont situées sur des rampes intra-plates-formes et des horsts. Malgré l'absence de traces d'activité volcanique au cours de la transition cambro-ordovicienne en Montagne Noire méridionale le régime distensif responsable du développement des paléotopographies en horsts peut être relié avec un régime géodynamique en extension. Ce dernier est reconnu dans d'autres secteurs du Massif central ayant enregistré des processus d'océanisation et une importante activité volcanique à la base de l'Ordovicien.

## INTRODUCTION

The stratigraphically sharp, first appearance of benthic complex communities related to the so-called 'Ordovician biodiversification' has been classically regarded as a record of evolutionary events, whereas alternative explanations involving drastic changes in environmental conditions are not frequently tested. The fact that trilobites and echinoderms commonly occur dominantly associated with linguliformean brachiopods, conodonts and other shelly taxa within carbonate deposits demonstrates that local diversification 'blooms' can be directly related to the dynamic sedimentation of depositional platforms. It seems, therefore, necessary to characterize

depositional processes and environments that controlled biodiversity fluctuations.

The environmental evolution across the Cambrian-Ordovician (C/O) transition is poorly known in southwestern Europe due to the lack of confident biostratigraphic correlations. However, the relative wealth in trilobites, echinoderms and linguliformean brachiopods in the Pardailhan and Minervois nappes [southern Montagne Noire; see Gèze, 1949, and Arthaud, 1970, for structural details] permits to envisage an improvement of the paleogeographic and paleoecological knowledge of the transition in the western Gondwana margin. The southern Montagne Noire (Languedoc, France) preserves a particu-

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larly significant record of the evolutionary radiations, immigration history and benthic community replacements displayed across the C/O transition. Its litho- and biostratigraphic relationships have been discussed, among others, by Sdzuy [1958], Boyer and Guiraud [1964], Courtessole [1973], Feist and Courtessole [1984], Ubaghs [1998], Shergold *et al.* [2000] and Vizcaïno *et al.* [2001]. Previous sedimentological works on the C/O transition and Lower Ordovician deposits of the southern Montagne Noire have concentrated on numerous slope-related lithofacies, frequently interpreted as 'flysch' deposits related to submarine slopes adjacent to shelf-margins [Hupé, 1959; Andrieux and Matte, 1963; Boyer and Guiraud, 1964; Alabouvette *et al.*, 1982; Berger *et al.*, 1990, 1993; Alabouvette and Demange, 1993]. However, despite the presence of metre-thick limestones across the C/O transition, they were practically ignored or undescribed in previous works. Recently, Álvaro *et al.* [2001] and Vizcaïno *et al.* [2001] discussed them revising and erecting two mixed (carbonate-siliciclastic) formations (the Val d'Homs and Mounio Formations, respectively) separated by the La Dentelle Formation. The first Tremadocian trilobite record was reported several centimetres below the Val d'Homs/La Dentelle boundary [Sdzuy, 1958]. The facies analysis and correlation of these limestone intercalations are key tools for the reconstruction of proximal-to-distal environmental polarities related to episodic syndimentary tectonic activity.

The purposes of this paper are to outline the sedimentological evolution of the southern Montagne Noire platform across the C/O transition, to distinguish the role of slope-induced deposition and carbonate productivity, and to discuss the sedimentary factors that controlled the replacement of major faunistic communities.

## GEOLOGIC SETTING AND STRATIGRAPHY

The Cambrian-Lower Ordovician rocks of the southern Montagne Noire are exposed within several thrusts of the Minervois and Pardailhan nappes (fig. 1). Correlation of this puzzle of disconnected outcrops, precise lithostratigraphic correlations and reconstruction of the dynamic stratigraphy are possible because some road and ravine sections are exposed with minor structural complexity, and because marker beds (such as glauconitic and iron-rich beds) commonly persist laterally.

After the discoveries of Middle Cambrian [Bergeron, 1888] and earliest Tremadocian [Sdzuy, 1958] fossil faunas in the southern Montagne Noire, several papers envisaged different interpretations for the apparent lack of Upper Cambrian fossil record, described for the first time by Feist and Courtessole [1984]: Boyer and Guiraud [1964] suggested the development of a stratigraphic hiatus or a major condensation across the Middle Cambrian-Tremadocian transition, while other authors, such as Courtessole [1973] and Shergold *et al.* [2000], claimed the existence of an unconformity at the boundary of the Val d'Homs and La Dentelle Formations in the Ferrals-les-Montagnes area. However, a recent lithostratigraphic revision of the C/O transition [Vizcaïno *et al.*, 2001] has permitted the recognition of a conformable sedimentary succession exhibiting

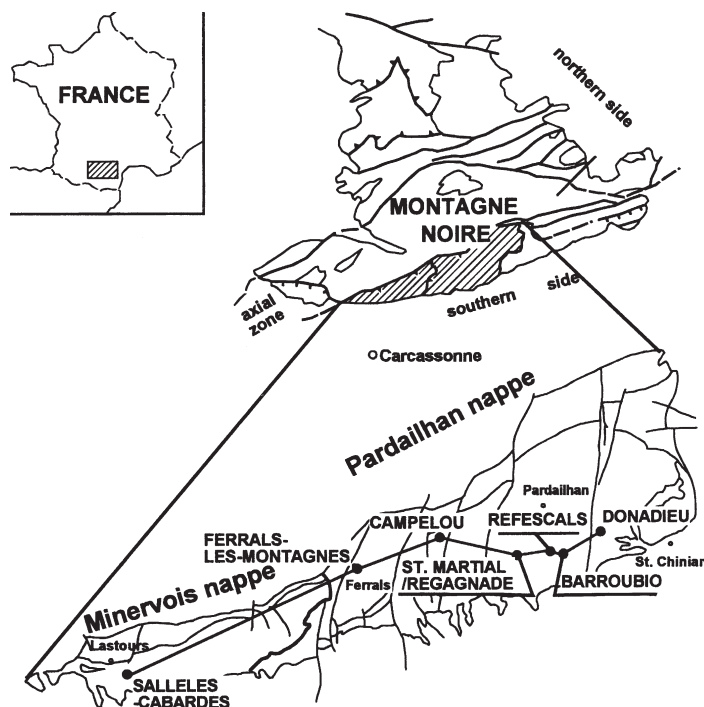


FIG. 1. – Geologic sketch of the Minervois and Pardailhan nappes (southern Montagne Noire, Languedoc) with location of the studied sections.

FIG. 1. – Schéma géologique des nappes du Minervois et de Pardailhan (Montagne Noire méridionale, Languedoc) avec localisation des coupes étudiées.

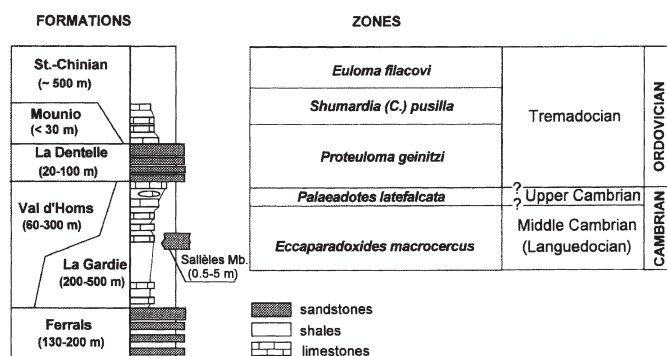


FIG. 2. – Stratigraphic units of the Cambrian-Ordovician transition from the southern Montagne Noire [after Álvaro and Vizcaïno, 1998; Álvaro *et al.*, 1998; Shergold *et al.*, 2000; Vizcaïno *et al.*, 2001]. Zones are defined by the FAD of their respective index-trilobites.

FIG. 2. – Unités stratigraphiques de la transition cambro-ordovicienne de la Montagne Noire méridionale [d'après Álvaro et Vizcaïno, 1998; Álvaro *et al.*, 1998; Shergold *et al.*, 2000; Vizcaïno *et al.*, 2001]. Les zones sont définies par l'apparition (FAD) de leurs trilobites index.

sharp, lateral variations in lithology, facies and thicknesses on which this paper is focused.

The lithostratigraphic units described and interpreted below are the La Gardie (partly), Val d'Homs, La Dentelle and Mounio Formations (fig. 2), which are underlain by the Ferrals Formations (Middle Cambrian), and overlain by the Saint-Chinian Formation (which seemingly comprises the Tremadocian-Arenigian transition). Biostratigraphic correlations are based on trilobite zonation summarized in Álvaro *et al.* [1998], Shergold *et al.* [2000] and Vizcaïno *et al.* [2001]. For more detailed lithostratigraphic informations see Álvaro *et al.* [1998] and Vizcaïno *et al.* [2001]. The La

Gardie Formation, 200 to 500 m thick, is composed of green shales with thin sandstone intercalations and centimetre- to decimetre-thick, shale/sandstone alternations. The formation contains the Sallèles Member (0.5-5 m thick), composed of amalgamated sandstone beds with millimetre-thick shale intercalations. The Val d'Homs Formation consists of green and purple shales containing centimetre- to metre-thick, white, reddish and purple, lenticular to bedded limestones and yellow dolostones; the formation displays a variable thickness from 60 up to 300 m thick, and can occur directly overlying both the Ferrals and La Gardie Formations. The overlying La Dentelle Formation (20-100 m thick) consists of white and grey, coarse- and medium-grained sandstones with rare green shale intercalations bearing isolated centimetre-thick, limestone and dolostone nodules; a discontinuous glauconitic siltstone, up to 0.5 m thick, occurs at its top. The Mounio Formation (up to 30 m thick) is composed of centimetric to decimetric alternances of nodular to bedded, reddish to purple, bioclastic limestones and shales, which laterally change into pale grey to yellow weathering, thin- to medium-bedded dolomites. Finally, the Saint-Chinian Formation (at least 500 m thick) consists of monotonous, dark-grey and green claystones and siltstones, bearing fine- to medium-grained sandstone intercalations and silica nodules, which cover directly both the La Dentelle and Mounio Formations.

The deformed and discontinuous nature of Cambrian-Lower Ordovician exposures in the southern Montagne Noire has long impeded the development of refined paleogeographic reconstructions. Although the large-scale facies architecture of the mixed carbonate-siliciclastic depositional system is not visible in outcrop, it can be tentatively constructed by integrating field mapping, facies analysis and biostratigraphy. The facies inventory, facies architecture and stratigraphic framework of the C/O transition are described and interpreted below.

## FACIES ASSOCIATIONS

Seven facies associations are described below, some of which displaying small-scale sequence arrangements described at the end of each description.

### Back-shoal, heterolithic beds

This association is well exposed in the Sallèles-Cabardès area, just underlying the Sallèles Member [Álvaro *et al.*, 1998] of the La Gardie Formation. The heterolithic complex consists of a rhythmic, millimetre-thick, lenticular-bedded shale to wavy and flaser-bedded sandstone intervals associated with channels displaying complex lateral accretion patterns. Trace fossils are rare and dessication features absent. Bedforms developed on the sand intercalations include current ripples, parallel and low-angle lamination, unidirectional cross-stratification truncated by inclined-to- subhorizontal reactivation surfaces, in some cases overlain by thin, subordinate, reversely oriented foresets (although distinct herringbone structures are not observed). Individual channels are about 20-80 cm wide and up to 30 cm thick (fig. 3.1). They occur both isolated and superposed as meander belts. Channel bottoms are slightly undulating, with local scours and sharp margins. Most of the channels contain shale and sandstone clasts as basal lags, as well as muddy, heterolithic infills

representing the progressive shallowing and infilling of abandoned channels. Lateral accretion surfaces within the channels are subhorizontal or irregularly erosive if modified by erosive bases. Dominant paleocurrents of channel axes are N-S, whereas reactivation surfaces range from WSW to WNW. This facies association is sharply truncated by a major erosive surface that separates it from the overlying fairweather wave-influenced, upper shoreface/foreshore Sallèles Member (described below).

The preservation of millimetre-thick, lenticular-wavy-flaser bedded claystone to sandstone alternations cut by meandering channels can be interpreted as a product of mixed deposition from suspension and traction transport. Heterolithic rhythmites are best developed in modern tidal environments in the inner reaches of macrotidal estuaries affected by meander channels with reversely oriented foresets [Meyer *et al.*, 1998; Myrow, 1998]. However, the study of further sections in the southern Montagne Noire is necessary to reconstruct such a facies mosaic.

### Shoal-dominated complexes

The fine- to medium-grained sandstones, identified in the Sallèles Member (La Gardie Formation) and the La Dentelle Formation, have erosive and abrupt lower and interbedded contacts, scouring into the underlying sediments. It comprises large-scale, trough and planar cross-beddings with sets ranging in thickness from 0.4 to 1.8 m, topped by symmetric ripples and ripple lamination. Smaller scale sets of trough cross-bedding, in the order of 10 to 30 cm, are volumetrically less important and occur interbedded with the larger sets. Some intercalated centimetre-thick, limestone nodules and layers have yielded trilobite, echinoderm and brachiopod debris, and other undetermined fossils. Paleocurrent measures from the dip azimuth of foresets of large-scale cross-bedding (thicker than 0.5 m), and plunge directions of trough axes demonstrate polymodal flow, dominantly towards the NNE.

The ubiquity of decimetre-scale cross-bedding indicates that the sandstones were originally deposited as large migrating bedforms. The predominance of trough shapes further shows that they were short-crested megaripples and sandwaves, where reactivation surfaces are rare. The association of sedimentary structures suggests a shallow platform dominated by wave activity, and minor storm reactivation related to interbedded erosive contacts. Episodes in which the bedforms ceased to migrate and were colonized by an open-sea benthic community can be recognized by the presence of marine benthic fossils within carbonate and shaly intercalations.

Sediments of the measured sections are generally incorporated into coarsening-upward sequences (0.8-1.2 m thick) : from bottom to top, almost all the sequences display a systematic succession in which the finer grained storm deposits are covered gradationally or sharply by the coarser grained sandstones. At the top of some sequences occur erosive and truncating surfaces, partly stained by iron oxides, and locally highly bioturbated by *Skolithos* and *Arenicolites*. Shoaling (prograding trends related to shallowing-upward fluctuations of the relative sea-level) during times of rapid sediment influx offers a simple and repeatable mechanism for creating these coarsening-upward sequences, topped by hardgrounds widely bioturbated.



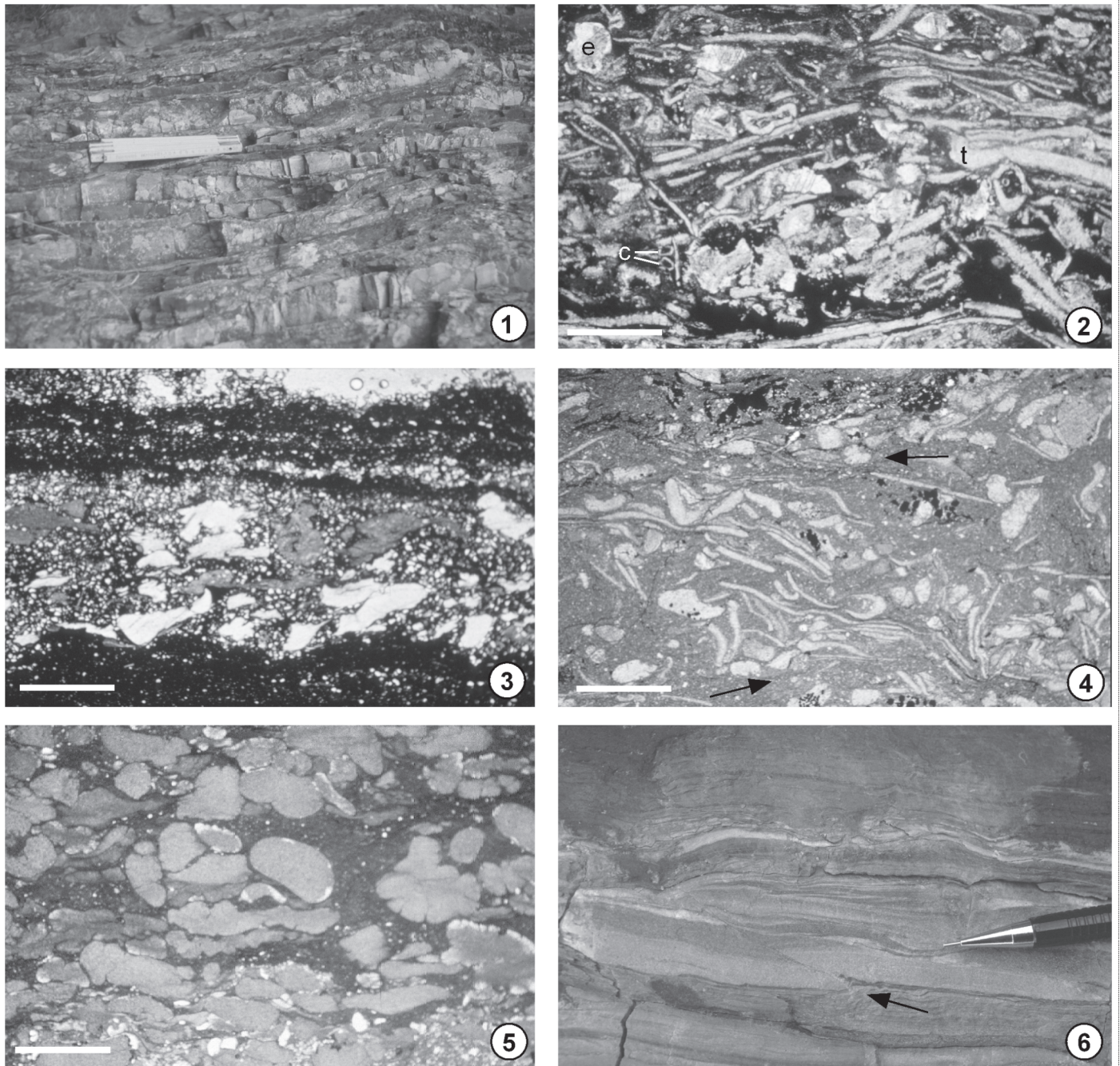


FIG. 3. 1. – Heterolithic facies association (La Gardie Formation) in the Sallèles-Cabardès area, showing laterally meandering channels and shoals alternating with shales (upper Languedocian, Middle Cambrian). 2. Packstones rich in trilobites (t), echinoderm plates (e) and conodonts (c) in a matrix rich in iron oxides; *Shumardia*-bearing limestones of the Mounio Formation in Combes de Barroubio (middle Tremadocian). 3. Laminated siltstones rich in iron oxides and bearing low-angle laminated fossil skeletons (mainly echinoderms and trilobites); *Proteuloma*-bearing purple shales at the Val d'Homs/La Dentelle boundary in Saint-Martial (lower Tremadocian). 4. *Palaeodotes*-bearing wackestones to packstones rich in echinoderms, trilobites and linguliformean brachiopods, exhibiting erosive surfaces (arrowed) and grading, interpreted as distal tempestites in the Val d'Homs Formation of the Refescals ravine (Upper Cambrian). 5. Siltstones to fine-grained sandstones rich in glauconitic pellets, located at the top of the La Dentelle Formation in Campelou (lower-middle Tremadocian). 6. Microfault (arrowed) located in a chaotic-bedded succession rich in slumps and sliding beds of the La Gardie Formation in Campelou (upper Languedocian, Middle Cambrian). Scale of figures 2, 3, 4 and 5 = 1 mm.

FIG. 3. 1. – Association des faciès hétérolithiques (formation de La Gardie) à Sallèles-Cabardès avec des chenaux et des barres méandriques alternant avec des schistes (Languedocien supérieur, Cambrien moyen). 2. Packstones à trilobites (t), plaques d'échinodermes (e) et conodontes (c) avec une matrice riche en oxydes de fer; calcaires à *Shumardia* de la formation de Mounio à Combes de Barroubio (Tremadocien moyen). 3. Siltites laminées riches en oxydes de fer, dont les bioclastes (principalement des échinodermes et des trilobites) sont disposés selon des laminations d'angle faible; schistes lie-de-vin à *Proteuloma* de la limite entre les formations de Val d'Homs et de La Dentelle à Saint-Martial (Tremadocien inférieur). 4. Wackestones et packstones à échinodermes, trilobites (*Palaeodotes*) et brachiopodes linguliformes, montrant des surfaces érosives (flèche) et des granoclassements, et interprétés comme tempestites distales dans la formation de Val d'Homs dans le ravin de Refescals (Cambrien supérieur). 5. Siltites à grès fins riches en grains de glauconite situés au sommet de la formation de La Dentelle à Campelou (Tremadocien inférieur-moyen). 6. Microfaille (flèche) située dans la succession chaotique à slumps et couches glissées de la formation de La Gardie à Campelou (Languedocien supérieur, Cambrien moyen). Echelle des figures 2, 3, 4 et 5 = 1 mm.



### Griotte limestone/shale alternations

This association, recognized both in the Val d'Homs and Mounio Formations, is composed of centimetre-thick alternations of bedded to nodular limestones and shales exhibiting reddish to purple colours. A close examination of good exposures indicates that these alternations are cyclic on several scales due to the variation in the limestone/shale ratio. The thicker carbonate beds (up to 20 cm thick) are dominated by packstone textures, including disarticulated to broken trilobites, echinoderm plates, hyolith-like shells, carbonate- and phosphate-shell brachiopods, and rarer conodonts and sponge spicules (fig. 3.2). Skeletons are arranged into parallel to low-angle laminations. The thinner limestone beds and nodules (less than 5 cm thick) are mainly wackestones rich in the same fossil assemblage, in some cases displaying grading, up to 1 cm thick and with erosive local contacts (fig. 3.3).

Cycles or alternations exhibit a repeated increasing-upward shale/limestone ratio, starting with limestone beds with stylonodular textures and millimetric clay seams, grading upwards into shales with isolated, thin, limestone nodules (as other Cambrian griotte facies described in southwestern Europe; see references below). The rhythmic alternation in lithology reflects periodic fluctuations in carbonate productivity and/or supply of fine siliciclastic sediments, the latter inhibiting the former. The thicker limestone intercalations have recorded the influence of bottom currents and waves (shoreface), while the thinner ones illustrate quieter conditions interrupted by high-energy pulses (offshore). The repeated (decimetre- to metre-thick) upward changes reflect deepening-upward trends where bioclast pavements reflect distal expressions of storm-induced processes. This transition indicates the decreasing effects of reworking by wave action and increasing storm currents in deeper offshore settings.

The most distinct feature of this facies association is its important lateral variation of thickness: e.g., in the Refescals ravine (fig. 1), several packages of 1-2.4 m decrease laterally (across 6-8 m) to 10 cm without the action of faults. Similar variegated limestone/shale alternations are known from the Lower-Middle Cambrian transition of southwestern Europe (named 'griotte' by their colour), and represent carbonate deposition on tectonically induced paleohighs, whereas shale deposition took place in relative, laterally equivalent depressions [Álvarez and Vennin, 1996, 1997]. High-frequency cyclicity involving the deposition of the griotte alternations in the Iberian Chains was related to Milankovitch-like, orbital forcing periods [Álvarez *et al.*, 2000].

### Storm-induced limestone/shale alternations

The Val d'Homs Formation is locally composed of alternating shale and bioclastic limestone nodules and beds (0.1 to 1.4 m thick) displaying sharp and erosive contacts. Bioclastic limestones consist of wackestones to packstones (fig. 3.4), whose main constituents are poorly-sorted trilobites, echinoderms, sponge spicules, calcite- and phosphate-shell brachiopods, conodonts, etc. In some cases, trilobites and echinoderms occur partly articulated, permitting recognition of biostratigraphically significant taxa [Shergold *et al.*, 2000]. Scattered, centimetre-thick grading and erosive bases are recognized. The terrigenous beds

consist mainly of clays, with micaceous fragments and silt quartz; sedimentary structures are scarce excepting bioturbation. The preservation of a non-fragmentary fossil record and high mud content alternating with fragmented skeletons and graded units, with erosive lower contacts, indicates that the substrate was episodically affected by storm events.

### Outer-platform, muddy beds

This consists of silty shales, with subordinate fine- and medium-grained sandstones, which comprise most of the La Gardie, Val d'Homs and lower part of the Saint-Chinian Formations. Shales are typically green to grey, and contain centimetre-thick, medium-grained sandstone intercalations exhibiting erosive bases and grading, and common bioturbation. They lack good stratification, which is suggested by millimetre-thick, finely crinkled, silty laminae and scarce centimetre-thick, carbonate nodules. Scattered soft-sediment deformation structures (mainly pseudo-nodules) also occur in many beds. Fossil fauna is sporadically abundant, preserved as articulated, disarticulated and broken debris, and comprises trilobites, cinctan echinoderms, phosphate- and carbonate-shell brachiopods, etc.

This facies association was probably deposited on offshore substrates, under essential calm-water conditions as evidenced by the dominance of siliciclastic mud, abundant bioturbation, and preservation of shelly fauna. The interbedded siltstone and fine sandstone beds were probably introduced as a result of storm surges.

### Glaucarenites

A distinct glaucarenitic marker bed (fine-grained sandstones in which glauconite minerals make up more than 25 % of the composition), up to 0.5 m thick, occurs locally overlying the La Dentelle Formation. Glaucarenites occur as well-rounded and medium-sorted pellets, 0.4-6 mm in diameter (fig. 3.5). Their deep emerald green colour corresponds to mature, highly evolved, K<sub>2</sub>O-rich glauconite mica [Odin and Fullagar, 1988]. These authigenic minerals are interpreted as deposited in open-marine environments with very slow deposition rates. The glauconite mineral pellets probably formed as a result of dissolution-precipitation processes [described by Chafetz and Reid, 2000], and were not derived by erosion of older rocks, although their fabric indicates a relative transport. The fact that the glauconite grains commonly have their long axes at low angles to bedding seems to rule out compaction as the main mechanism to explain their grain orientation. The fact that the glauconite grains commonly have their long axes at low angles to bedding seems to rule out compaction as the main mechanism to explain their grain orientation. This glauconite-dominated layer does not cover the whole outcrops of the Minervois and Pardailhan nappes. The lack or finely dispersion of glaucarenites in the griotte-like limestones can be related to the different sedimentation rates on carbonate and terrigenous substrates.

### Slope-related deposits

These deposits consist of shales and sandstone alternations episodically characterized by a chaotic arrangement of contorted beds. Truncation surfaces, intraformational slumps

and syn-sedimentary bedding distortion are common in the La Gardie Formation, some outcrops of the Val d'Homs Formation devoid of limestone intercalations and, locally, the lower part of the Saint-Chinian Formation. Truncation surfaces, some of which involve sediment thickness of several tens of metres, can be traced laterally up to 50 m, and are revealed by dip discordances bounded above and below by undisturbed sediments. Intraformational slumping has resulted in severe deformation of entrained material, lithologically similar to the underlying sediments, which displays a range of brittle 'firm' and soft-sediment deformation, highly contorted and folded. Depending on location, underlying sediments were either lithified (shear beds and laminae, sharply truncated and discordant) or unlithified (steeply dipping sediments, up to 60°, squeezed and contorted) at the slump interface. On a smallest scale, synsedimentary normal microfaults (fig. 3.6) and sedimentary boudinage have resulted from extensional stresses within a poorly lithified to unlithified sediment mass. Isolated and rare boulders, up to 50 cm in diameter, are oriented parallel to bedding, and contain a wide range of lithofacies. Paleocurrents deduced after analysis of the previous structures are not uniform, which implies development of a complex paleotopographic framework.

The above-described structures can exhibit either chaotic or amalgamated patterns, and are interpreted as having undergone different types of down-slope movements by basal sliding of plastic to semi-rigid sediment masses. The reworked material was developed on slope(s) close to the sedimentary environments from which they were derived. The evidence of post-depositional down-slope movement suggests the presence of a reasonable slope, while taphonomic patterns of the fossil record (preserved as complete to incompletely disarticulated skeletons) indicate deposition within offshore conditions. The lack of breccia deposits and rhythmic turbidites suggests low-angle slopes, in contrast with the conventional steeped submarine fan models, which imply base-of-slope to basin deposition dominated by turbidites [Morton, 1993; Shanmugam *et al.*, 1996].

## PALEO GEOGRAPHIC OUTLINE

Using the interpretations presented in the preceding section, the La Gardie/Val d'Homs, La Dentelle and Mounio Formations are inferred to represent an overall transgressive-regressive-transgressive composite framework, comprising different orders of relative sea-level changes that will not be described in detail in this preliminary work. Therefore, only large-scale depositional systems will be documented below. The depositional models are summarized in a time-sequence diagram of lateral facies relationships (fig. 4), in which the southwestern exposures contain a much higher siliciclastic/carbonate ratio and coarser terrigenous sediments due to episodic intermixing of land-derived material, and are here interpreted to be closer to the shoreline.

The La Gardie Formation cropping out in the westernmost Sallèles-Cabardès area would represent a tidally influenced depositional system cut by landward migration of the Sallèles shoal complex, both of them illustrating tidal- and wave-dominated end-members. The depositional system is clearly retrogradational as evidenced by a vertical succession from tidal (estuarine ?) flats and channels (back-shoal heterolithic beds of the La Gardie Formation), covered by

shoreface to foreshore shoals (shoal complexes of the Sallèles Member), and capped by the Val d'Homs offshore sediments. The proximal, inner-platform, Sallèles Member consists of terrigenous sediments transported from the nearshore and reworked *in situ* by the complex interaction of unidirectional and oscillatory currents generated by waves and storms : shoreface sediments evidence reworking by shoaling fair-weather and waning storm waves. The Val d'Homs, outer-platform sedimentation was dominated by suspension setting of mud under fair-weather conditions punctuated by sharp storm events. The difference in sedimentation rates of both carbonate and siliciclastic substrates suggests establishment of topographic highs on the platform where isolated windows of carbonate productivity were rhythmically intense in the griotte-like limestones, surrounded by deposition of terrigenous sediments on adjacent lows or depressions. This was laterally accompanied by relatively common high-energy currents transporting sediment down-slope as a result of high-slope instabilities resulting in slumping, sliding and debris flow. In contrast, coeval deposition on intra-platform ramp settings was marked by much quieter conditions where substrate stability was higher. The retrogradational (transgressive) patterns of the La Gardie and Val d'Homs sedimentary systems are recognized as onlapping geometries on the Ferrals/Val d'Homs and the La Gardie/Val d'Homs boundaries (fig. 4). The first occurrence of the Val d'Homs limestones is diachronous and perfectly datable by trilobites, from upper Languedocian (Middle Cambrian) in Refescals to Upper Cambrian in Ferrals-les-Montagnes.

The subsequent La Dentelle deposition occurred when shoreline and nearshore facies prograded across the tectonically induced paleotopography, as a result of an increase in terrigenous supply and establishment of regressive conditions. During deposition of the La Dentelle Formation, the inherited tectonically induced paleorelief must have disappeared or highly attenuated, since the coarse-grained siliciclastics extended to the whole platform, and no tectonic interruptions are recorded.

At the end of the La Dentelle progradation, the abrupt relative sea-level rise caused a marked change in depositional patterns. A correlatable glauconite documents a major transgressive surface reflecting a sharp change in the style of sedimentation and the flooding of the platform. Continued transgression during earliest Tremadocian times flooded most of the platform. Offshore muds dominated sedimentation (Saint-Chinian Formation) with patches of high carbonate productivity (Mounio Formation) across early-mid Tremadocian times. The mixed carbonate-siliciclastic deposition includes shallow-water hydrodynamic (griotte-like) limestones on tectonically induced topographic highs near the Combes de Barroubio area. Finally, the middle Tremadocian transgression went on as suggested by the flooding of the platform, the end of carbonate productivity on horsts, and the widespread extent of the Saint-Chinian shales.

As described above, the style of sedimentation was episodically interrupted by drastic, highly energetic sedimentary processes, resulting in rapid lateral changes in both facies and thicknesses. These events are recorded as two distinct facies associations : (i) griotte-like, rhythmic alternations of limestone and shales, and (ii) slope-related deposits. This framework indicates that the Minervois and



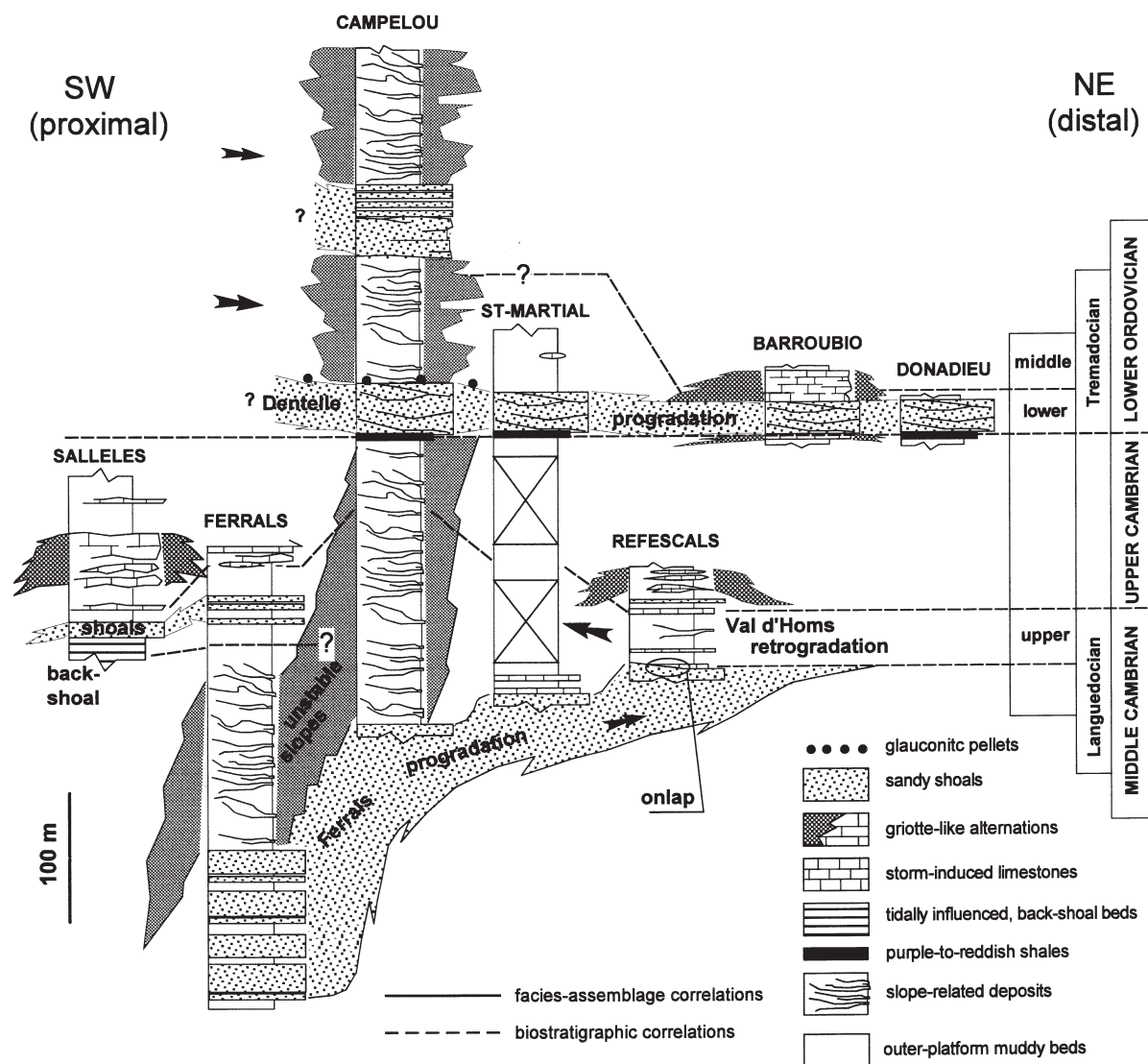


FIG. 4. – Sedimentary architecture of the Cambrian-Ordovician transition in the southern Montagne Noire based in the facies associations described in this paper, and the chronostratigraphic horizons summarized in figure 2. See figure 1 to situate geographically the studied sections.

FIG. 4. – Architecture sédimentaire de la transition cambro-ordovicienne dans la Montagne Noire méridionale selon les associations de faciès décrites dans le texte et les horizons chronostratigraphiques résumés en figure 2. La figure 1 montre la situation géographique des coupes étudiées.

Pardailhan nappes preserve a set of Upper Cambrian-Tremadocian intra-platform ramps with different subsidence rates, and intervening slopes related to major episodes of tectonic instability. It is noticeable that no tectonic breaks have been encountered within the coarse-grained La Dentelle Formation: the unbroken nature of their metre-thick sequences, deposited in environments ranging from foreshore to shoreface, indicates that the discontinuous slopes were masked by sediment-influx.

#### PALEOGEOGRAPHIC CONTROL ON FAUNISTIC COMMUNITY REPLACEMENTS

The distribution and replacements of benthic communities across the C/O transition are directly controlled by the transgressive-regressive trends, the migration of the centre of carbonate productivity, and the paleogeographic patterns described above. Both the late Languedocian-late Cambrian and the mid Tremadocian transgressive trends produced a noticeable reorganization of benthic marine communities.

Global transgressive patterns opened routes for invaders from other margins of Gondwana. If the Leonian-Caesaraugustian (Middle Cambrian) benthic fauna displays a Mediterranean biogeographic affinity, in some cases evidencing a connection of open-sea platforms from Turkey to Newfoundland [Álvaro *et al.*, 1999], the following late Languedocian-late Cambrian transgression is characterized by distinct benthic communities. The most significant reorganization that occurred in marine ecosystems after the early-mid Languedocian regression was the immigration of new trilobite species displaying Australo-Sinian affinities [Shergold *et al.*, 2000], and linguliformean brachiopod genera reflecting a widest provenance from the northern Gondwana margin (northern China, Antarctica and Australia), Kazakhstan and Siberia [González-Gómez, 2001].

The late Cambrian-earliest Ordovician faunistic communities disappeared with the onset of siliciclastic-dominated, shoaling deposition of the La Dentelle Formation. The Mounio and Saint-Chinian Formations represent the

re-establishment of carbonate and shaly, transgressive deposition. Unfortunately, the lower Tremadocian fossil assemblage is less known, as only trilobites are described. The fossil record associated with *Proteuloma geinitzi* is composed of relatively eurytopic species (they occur both in shaly and carbonate substrates), found in Bohemia, Germany and Sardinia [Sdzuy, 1958; Loi *et al.*, 1995].

Most macrofaunal skeletal associations in siliciclastic platform environments were dominated across the Cambrian-Ordovician transition by trilobites and cinctans, although brachiopods and hyoliths became locally important numerically. In contrast, in all the carbonate units, mechanical destruction of skeletal material into bioclastic debris in moderate to high-energy environments produced large quantities of bioclastic limestones, where cinctan and pelmatozoan echinoderms, conodonts, linguliformean brachiopods (acrothelids, acrotretids, lingulids, paterinids and siphonotretids), spiculate sponges and trilobites were major contributors to sediment.

In summary, the carbonate productivity in isolated horsts and intra-platform ramps favoured the preservation of distinct pelmatozoan-sponge meadows, in which the immigration of linguliformean brachiopods and conodonts (both of them phosphatic in composition and easy to be studied after acid etching) explains the increase in biodiversity in some reduced areas, surrounded by low-diversity muddy substrates.

## CONCLUSIONS

The facies succession of the La Gardie/Val d'Homs, La Dentelle and Mounio Formations presents a general transgressive-regressive-transgressive composite trend, correlatable from middle Languedocian (uppermost Middle Cambrian) to middle Tremadocian (Lower Ordovician) rocks.

On the basis of field observations, it appears that the 'unstable slope model', traditionally interpreted in this area, can be applied to some (but not all) outcrops of the La Gardie and Val d'Homs Formations: this implies a wide development of low-angle slides and slopes, intraformational truncation, discordant surfaces and slump folds, and record of sharp lateral variations of facies and thicknesses. The platform apparently lacked major slope breaks due to the absence of distinct breccia and turbidity deposits. However, the development of slumping deposits and other slope-re-

lated sedimentation is not generalized due to the more stable depositional patterns recorded on some coeval intra-platform ramps, characterized by the establishment of mixed (carbonate-siliciclastic) substrates. At least a major 'collapse area' [*sensu* Morton, 1993] or region where a disproportionate amount of sediments were affected by sediment instability can be identified in the Ferrals-Campelou area (western Pardaillan nappe). Several factors may have helped to initiate it, such as instability of soft semi-cemented sediments on the slopes, and growth fault steepening the slope platform. Episodic faulting reactivation of slopes gives a plausible explanation for this stratigraphic framework, in which emergent conditions as a consequence of uplift or sea-level fall are not reported. Although the C/O transition of the southern Montagne Noire did not record volcanic events but a rather distensive regime inducing paleotopographies, a major extensional regime was recorded at the beginning of the Ordovician in other areas of the French Massif Central involving oceanization (marked by the formation of new oceanic crust preserved at present as ophiolite wedges) and major magmatic activity [see a summary in Ledru *et al.*, 1994].

Similar successions of the same age in the western Mediterranean area lack carbonate-dominated deposits such as those reported here: their better preservational conditions allow reconstructions of the complex benthic communities developed in very strict depositional environments, composed of echinoderm-sponge meadows. Paleogeographic reconstructions made in connection with paleoecological studies indicate a number of paleoenvironmental changes traceable across the studied sections. This contribution is a new attempt to analyse the C/O transition on the southern Montagne Noire in the light of relative sea-level changes and community replacements, allowing better comparison of major events with neighbouring platforms of the western Gondwana margin. Further studies are in progress (such as conodont and brachiopod systematic and biogeographic analyses) that will improve this preliminary sketch.

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